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STUDENT REPORT

ELECTRONIC COMBAT OVER THE THIRD REICH

MAJOR STEPHEN R. FRALEY 88-0975

"insights into tomorrow"

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Submitted to the faculty in partial fulfillment of requirements for graduation.

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The purpose of this study was to determine the factors governing the effectiveness of American and British electronic combat operations during the World War II bombing campaign against Germany. The study examines the characteristics and effectiveness of the Allied bombers and jammers, and the German flak, fighters, and electronic order of battle. The study concludes that the Germans could work around the Allied electronic combat efforts if enough elements of the defensive network were not decisively countered.

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PREFACE

Electronic Warfare has been a challenging field of endeavor since its inception It is characterized by a continual struggle between measures taken to defeat an enemy and the countermeasures taken by the other side to regain the initiative. This action takes place in the laboratory, as well as on the battlefield. A classic case of this struggle occurred during the World War II bombing campaign against Germany. The inspiration for this study is due to the author's father, Rex C. Fraley, a former B-17 waist gunner in 15th Air Force. The "Lone Wolf" missions he flew out of Italy to targets over Germany and Austria were probably in support of the British night raids detailed in this study. The author wishes to thank his wife, Charlene, for her patience during the research and writing of this study. The assistance of Lt Col Doug Deabler, faculty advisor, is also gratefully acknowledged.

ABOUT THE AUTHOR

Major Fraley attended Undergraduate Navigator Training and Electronic Warfare Officer Training at Mather Air Force Base in California. After attending B-52 Combat Crew Training, he was stationed at Fairchild Air Force Base in Washington where he served as an instructor B-52 Electronic Warfare Officer, and on the wing staff as the Electronic Warfare Simulator Supervisor. Major Fraley was then stationed at Edwards Air Force Base in California as a Defensive Systems Officer in the B-1 Combined Test Force. He then attended the USAF Test Pilot School and graduated as a Flight Test Navigator. After graduation, he was reassigned to the B-1 Combined Test Force where he flew B-1 test missions, production acceptance flights, and test support missions to test the B-1 electronic warfare systems. Major Fraley has over 2000 hours in several diverse types of aircraft, and has been qualified in the B-52, B-1, F-111, and F-4. Major Fraley has a bachelor of science degree in Aerospace Engineering from the University of Missouri at Rolla, and a master of science degree in Mechanical Engineering from California State University at Fresno. He has completed Squadron Officers School by correspondence and in residence. He has completed Air Command and Staff College by correspondence, and was assigned there as a student in residence when this study was conducted.

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GLOSSARY

ABC	Airborne Cigar
AI	Airborne Intercept(or)
BMS	Bombardment Squadron
C-1	Lichtenstein Radar (early model)
C^3	Command, Control, and Communications
DF	Direction Finding
ECM	Electronic Countermeasures
ECCM	Electronic Counter Countermeasures
EOB	Electronic Order of Battle
EW	Early Warning
FuG	Funkgerat
FuMG	Funkmessgerat
FW	Focke-Wulf
GCI	Ground Control Intercept
He	Heinkel
HF or H/F	Height Finder (Radar) / High Frequency (Radio)
HQ	Headquarters
H2S	British Airborne Radar (known to the Germans as "Rotterdam")
H2X	American Airborne Radar (known to the Germans as "Meddo")
IFF	Identification Friend or Foe
JD	Jagddivision
Ju	Junkers
KHz	Kilohertz
KIAS	Knots Indicated Airspeed
KTAS	Knots True Airspeed
kW	Kilowatts
Max	Maximum
Me	Messerschmitt
MHz	Megahertz
N/A	Not applicable
mm	Millimeter
MPH	Miles Per Hour
NM	Nautical Mile
No.	Number
RX	Receive
SN-2	Lichtenstein Radar (late model)
TX	Transmit
UHF	Ultra High Frequency
USSBS	United States Strategic Bombing Survey
VHF	Very High Frequency

EXECUTIVE SUMMARY

REPORT NUMBER 88-0975

AUTHOR(S) MAJOR STEPHEN R. FRALEY, USAF

TITLE ELECTRONIC COMBAT OVER THE THIRD REICH

I. Purpose: The purpose of this study is to determine what factors governed the effectiveness of American and British electronic combat operations during the World War II bombing campaign against Germany.

II. Problem: There is a perception that electronic combat played a minor role in the eventual success of the strategic bombing campaign against Germany. However, there are principles that can be learned from this conflict regarding factors to increase the effectiveness of electronic combat operations. If all factors are not considered, incorrect lessons can be learned about why some equipment or tactics work better than others.

III. Objectives: This study has been divided into six areas of research and analysis, as summarized below.

A. Determine the characteristics of the American and British bombers, and the German fighters and flak batteries.

B. Review the tactics used by the Americans, British, and Germans.

C. Determine the characteristics of the German Electronic Order of Battle (EOB).

D. Determine the characteristics of the electronic combat equipment used by the Americans and British to counter the German EOB.

E. Determine how effectively the American and British electronic combat equipment countered the German EOB.

F. Analyze why the degree of effectiveness of the electronic combat equipment was achieved.

IV. Findings: The Germans had a complex air defense system that the Allies defeated after a prolonged series of measures and countermeasures. Window, chaff, Mandrel, Tinsel, Airborne Cigar, Piperack, and Carpet provided definite advantages as the Allies introduced them into the conflict, and provided temporary decreases in loss rates to make up for the long exposure of the bombers to radar, flak, and fighters. These gains were temporary because the pace of conflict allowed the Germans time to develop new tactics or equipment to make up for each countermeasure. However, eventually the Germans ran out of options. This occurred in the late summer of 1944 when several factors almost simultaneously shut down the German defensive effort. During this time the Germans lost the use of the early warning radars in France. This allowed the British to approach Germany at a lower altitude and reduced the warning time of a raid. The British also changed their tactics to increase the number of spoofing raids. The Allied bombing effort had reduced the fuel available for the fighter force. These factors put additional strain on the German defenses. The Americans finally had enough jammers to protect their bombers from flak. The British finally were able to defeat most of the night fighter and flak radars when they got jammers with sufficient frequency coverage. The Mosquito night fighters forced the Germans to turn off their IFF. In essence, the Allies were able to cut or disrupt all of the links in the German defensive network and render it ineffective.

V. Conclusions: While temporary advantages occurred as the Allies introduced various countermeasures, it was not until they cut several links almost simultaneously that the Germans lost the air battle. In the case of the night fighters, the British then kept the pressure on so that the Germans could not work around the countermeasures. In the case of the daylight raids, the American jamming and chaff increased the flak ammunition cost to the Germans, but it did not cut the links required to defeat the German's last option, barrage firing.

VI. Recommendation: Recommend the project sponsor incorporate this study into the Strategic Air Command historical data base.

Chapter One

INTRODUCTION

The purpose of this study is to determine what factors governed the effectiveness of American and British electronic combat operations during the World War II bombing campaign against Germany.

BACKGROUND OF THE PROBLEM

There is a perception that electronic combat played a minor role in the eventual success of the strategic bombing campaign against Germany. Some authorities say the primary roles were played by the loss of the radars in France after D-Day and the German fuel shortage late in the war (5:138-139; 6:24; 15:149). The electronic combat role is overlooked for a variety of reasons. The first is that this subject was classified until the early 1960s (12:vii). The second is the lack of appreciation for the complex nature of the German air defenses, and their resilient nature. Finally, there is a tendency to look for simple solutions to the complex problems posed by the German air defense system, and how it was finally defeated. For example, there is a tendency to assign the defeat of the flak defenses to chaff or window. The German capability to work through the chaff and window is often overlooked. Similarly, there is a tendency to stop any analysis after examining the important role played by American long range fighter escorts in defeating the German day fighters. Little regard is given to the total problem of defeating the German air defense system, to the other factors that could have played a role in the outcome, or to the British strategic bombing experience.

SIGNIFICANCE OF THE PROBLEM

There are principles that can be learned from this conflict regarding factors to increase the effectiveness of electronic combat operations. If all factors are not considered, incorrect lessons can be learned about why some equipment or tactics work better than others. This problem is significant since it leads to incorrect conclusions of how to learn from, and reduce losses in, future conflicts.

ASSUMPTIONS AND LIMITATIONS

There are some assumptions and limitations to the scope of this study. First, it deals mostly with the Allied and German effort at the mature stage of the air war, which is assumed to have occurred during and after the summer of 1944. At this stage, the Allied electronic combat effort consistently denied the initiative to the Germans, and they had additional countermeasures available to defeat German initiatives under development (12:195, 237-243). Second, it only deals with the conditions encountered on raids into Germany. These conditions were mass formations of bombers, large numbers of fighters (Allied and German), and a complex air defense network. Third, only aircraft and equipment that made a significant contribution to the electronic combat are presented here. For example, the Me-262 jet showed promise as a night fighter, even against the elusive Mosquito. However, it was not deployed in time to make a difference in the outcome (1:213-214, 220).

PREVIOUS STUDIES

The BDM Corporation and the U.S. Central Intelligence Agency have written previous studies in this area. The BDM Corporation study was sponsored by the Defense Nuclear Agency and is titled: A Historical Survey of Counter-C3 (3:--). The Central Intelligence Agency study was written by its Office of Research and Development and is titled: Thoughts on the Cost-Effectiveness of Deception and Related Tactics in the Air War, 1939 to 1945 (19:--). Both of these studies dealt with the integration of the many factors that affect the success of a military operation, especially in achieving surprise. However, they did not fully cover some of the factors governing electronic combat effectiveness.

OBJECTIVES OF THIS STUDY

This study has been divided into six areas of research and analysis, as summarized below. Each area is the subject of a separate chapter.

1. Determine the characteristics of the American and British bombers, and the German fighters and flak batteries.

2. Review the tactics used by the Americans, British, and Germans.

3. Determine the characteristics of the German Electronic Order of Battle (EOB).

4. Determine the characteristics of the electronic combat equipment used by the Americans and British to counter the German EOB.

5. Determine how effectively the American and British electronic combat equipment countered the German EOB.

6. Analyze why the degree of effectiveness of the electronic combat equipment was achieved.

Chapter Two

CHARACTERISTICS OF THE ANTAGONISTS

THE GERMAN DEFENSES

By the summer of 1944, the Germans had an extensive air defense system. When first developed in 1942, it consisted of a simple network of coast watchers, listening posts, manually controlled searchlights, flak guns using optical sighting, and day fighters (1:15-20). As detailed below, the system evolved into a sophisticated network of radar controlled fighters, radar controlled searchlights and flak batteries, early warning and Ground Controlled Intercept (GCI) radars, and radio-direction finding devices.

The German Fighters

Day Fighters. The day fighters were single-seat, single engine, high speed aircraft. These fighters were characterized by aircraft such as the Me-109 and FW-190 (14:95). The Me-109 had a maximum speed of 392 KTAS at 19,685 feet (Bf 109K-4), while the FW-190 had a maximum speed of 332 KTAS at 19,685 feet (FW-190A-8) (15:260). The Germans equipped them with the Y-control VHF radio communications and navigation system (11:35). Some day fighters also had radar and homing devices to aid their use in the night fighting role (1:138). They had machine guns and rockets for armament (14:39; 15:260).

Night Fighters. The night fighters were sophisticated twin engine aircraft with a two or three position crew consisting of a pilot and radio/radar operator(s). These aircraft were characterized by fighters such as the Me-110, Ju-88, and He-219 (4:6; 14:92-93). They were slower and less maneuverable than the day fighters. For example, the maximum speed of the various models of the Ju-88 ranged from 263 to 291 KTAS at 19,685 feet (1:134; 15:267). The drag of the externally mounted radar antenna reduced their maximum speed by 22 to 43 KTAS (1:40, 69, 137). The night fighters had a longer endurance than the day fighters, but it was still a constraint to their operations. For example, the Me-110 had a sortie endurance of only two hours (1:18). The night fighters had an HF radio and the Y-control system as well as radar, infrared, and homing systems (1:126). These fighters had upward firing guns so the pilot could shoot at the bombers from below (1:66-67).

The German Flak Defenses

German flak units provided a point defense in the target areas. Each flak battery had a Wurzburg or Mannheim radar, searchlights, a fire control computer, an optical range finder, and 4 to 8 guns with calibers of 88 mm, 105 mm, or 128 mm. The Wurzburg radar or the optical range finder tracked the bomber to provide the range and bearing fire control information. The flak shells had timers that had to be set to make them explode in the vicinity of the bomber (12:274).

Flak accuracy depended on the speed and range of the target. This information was used to set the shell timer and was critical since the 88 mm shells were inadequate to bring down a B-17 unless they exploded within 16 feet of it (11:5, 10; 14:8). For example:

> [With] an aircraft flying at 20,000 feet at a slant range of [4.8 nautical miles], an 88 mm shell would take about 19 seconds to cover this distance. In this time, a B-17 at [195 KTAS] would fly just over a [nautical mile]. So, for an accurate engagement, at the time of firing the gun, the barrel had to be aligned on a point in the sky more than a [nautical mile] in front of the aircraft (12:274).

The maximum effective range for the 88 mm Flak 41 gun and the 105 mm Flak 39 was 4.8 nautical miles (NM) when time fused shells were used. The maximum effective range of the 128 mm Flak 40 gun was 5.9 NM (11:10). The Germans had to fire an average of 10,000 rounds to bring down an aircraft in 1945, with 30,000 to 50,000 rounds being fired during a raid (11:24).

Use of the optical range finder required good weather and a skilled operator to be effective, so Wurzburg radar information became the preferred method for providing fire control inputs. If the radar was not available at night, the optical range finder could be used to find the approximate range if a searchlight was illuminating the target. The resulting fire was not very accurate (11:4; 12:282; 14:21).

The German Warning and Control Network

Radar Warning Network. The Germans developed an extensive radar network for early warning of bomber raids, controlling fighter intercepts, and coordinating the flak defenses (15:214-219). They had 740 radars in Western Europe for this purpose (10:470). They installed early warning radars, such as the Freya, along the coasts and the French/German frontier to provide warning of a raid. See Figure 5. Further inland, this same type of radar directed the Wurzburg tracking radars onto individual bombers (13:111). The Germans classified radar installations as first, second, or third rank stations, depending on the level of sophistication for conducting intercepts. First rank stations had a Jagdschloss GCI radar, a height finder radar, an early warning radar, and a Wurzburg installed. The second rank stations had an early warning radar and a Wurzburg. The third rank stations only had an early warning radar. The first and second rank stations were night intercept capable if they had two Wurzburgs. Ground observers filled in the gaps between radars to report low flying aircraft (11:31-33).

Radio Reconnaissance Service. The German radio reconnaissance service, known to the British as the Y-service, used direction finding facilities to locate the British bomber stream and the American formations. These facilities plotted the progress of the bombers by determining the direction of their radio, and H2S or H2X radar emissions. They could also trigger the British IFF to determine the location of individual bombers in the stream (11:38; 13:176, 179; 14:82). This was critical since " . . . it only needed one aircraft to leave its I.F.F. on for the whole bomber stream to be betrayed" (10:390). The radio reconnaissance service passed this information to the radar stations so they could " . . . give special attention to the direction of probable approach" (11:39).

Control Network. The fighter divisions, known as Jagddivisions, directed the air battle based on the locations of the bombers and fighters. See Figure 5. The radars and the radio reconnaissance service passed the location of the bombers to the sector reporting centers, and then to the fighter division flight reporting centers. The location of the fighters came from the fighter control service, the radio reconnaissance service, and reports from adjacent fighter divisions (11:33-34). For night intercepts, the Germans split up each area to be defended into zones. Each zone had fighters assigned to it as well as early warning radars, searchlights, sound locators, light and radio beacons for night fighter navigation, and tracking radars. A string of zones known as the Kammhuber line ran from Denmark to Switzerland. The Germans used this line for the close control of night fighters (10:267-269; 13:143). They established light and radio beacons in other areas to concentrate night fighters for use in more loosely controlled intercepts (13:146).

THE ALLIED BOMBERS

The B-17, B-24, and Lancaster were heavy bombers that penetrated at low speeds. This resulted in penetrations with long durations in the enemy radar, flak, and fighter coverage. The Mosquito was faster, but could not carry large bomb loads.

The B-17 Flying Fortress

The B-17 Flying Fortress was a heavy bomber with a maximum speed of 249 KTAS at 25,000 feet (B-17G). Tactical speed was 156 to 187 KTAS at the same altitude. In a tactical climb, it took the B-17 1-1/2 hours to reach 25,000 feet (7:159). The service ceiling was 35,600 feet (15:239-240). It had machine guns mounted in the nose, tail, top, bottom, and sides of the fuselage (15:240). The B-17 could navigate and bomb under all weather conditions using the H2X radar, which operated at a frequency of approximately 10,000 MHz (7:240-241).

The B-24 Liberator

The B-24 Liberator was a heavy bomber with a maximum speed of 252 KTAS at 25,000 feet (B-24H). Tactical speed was 178 KTAS at the same altitude. The service ceiling was 28,000 feet. It had machine guns mounted similarly to the B-17, and also had the H2X radar. It flew at lower altitudes than the B-17 because of its poor formation handling qualities (7:164-174). Besides using it as a bomber, the Americans also used the B-24 for specialized jamming missions, including providing support to the British (15:78-79).

The Avro Lancaster

The Avro Lancaster was a heavy bomber with a maximum speed of 213 KTAS at sea level. The Lancaster could fly faster than most of the German night fighters, but most penetrations were flown slower to increase its range (1:32, 69, 133; 15:235). The service ceiling was 22,000 feet (15:235). The Lancaster had machine guns mounted in the nose, tail, and on top of the fuselage (15:235). The gunners had a poor field of view from their gun turrets. In addition, the guns had a shorter effective range than the German fighters for most of the war (8:174; 9:163). The British equipped the Lancaster with the Monica tail warning radar to warn of night fighter attacks (13:139). The Lancaster could navigate and bomb under all weather conditions using the H2S radar, which operated at a frequency of approximately 3000 MHz (7:240; 9:124).

The DeHavilland Mosquito

The DeHavilland Mosquito was a medium bomber with a maximum speed of 354 KTAS at 26,000 feet (Model BXVI). The service ceiling was 37,000 feet (15:248). The Mosquito was faster than the German night fighters at the high altitudes it usually flew at, and was difficult to shoot down. It also had a small radar signature which made it difficult for ground radars to detect in time to vector fighters to intercept it (1:87; 8:195-196; 13:138). Despite its small bomb load, these characteristics allowed it to perform several specialized tasks. These included use in pathfinder forces for the main bomber stream, spoofing forces in fake bomber streams, night fighter escorts for British bombers, and dispensing window to cover the main and spoofing bomber streams. In the pathfinder role, the Mosquitoes used either the Oboe or Gee radio navigation systems. In the night escort role, the British equipped the Mosquito with an airborne intercept (AI) radar, the Monica tail warning radar, the Serrate homing receiver, and the Perfectos IFF interrogator (9:125, 144, 189-190; 15:36, 245).

Chapter Three

TACTICS

ALLIED TACTICS

The Allies developed tactics to assure the destruction of the target and increase the effectiveness of bomber defense (7:37; 9:83). Not all aircraft had equipment to find the target under all conditions, so they used pathfinder forces to mark the target with flares or provide the bomb release signal for the rest of the bombers. The Allies equipped these forces with the H2S or H2X radar, or the Oboe radio navigation system. (7:46-49; 9:166; 10:275).

American Tactics

The Americans built their tactics around the defensive box formation. The first box formations had as few as 18 to as many as 54 aircraft to provide mutual protection from fighters (7:43). However, the tight boxes required to fend off fighter attacks tended to increase flak losses. When long-range fighter escorts became available, and the German day fighter threat diminished, the Americans reduced the number of aircraft in the box to 9 or 12 and dispersed the box formations to reduce flak losses (7:43; 12:105-106).

The B-17 formations flew at altitudes of 24,000 to 27,000 feet, while the B-24 formations ranged from 20,000 to 24,000 feet (7:21, 167). They used an indicated airspeed of 113 to 130 KIAS before the target, and 139 to 156 KIAS after the target (7:25). A typical formation was 1170 feet wide, 800 feet long, and 1050 feet in height. There was 1-1/2 miles between formations (7:42-43). The lead Combat Wing or a formation of Mosquitoes dispensed chaff, but only in the target area (7:97-98, 201; 12:99).

Special mission aircraft of the 36th Bombardment Squadron (BMS) orbited off the Dutch coast and jammed the German radio reconnaissance service to prevent them from monitoring American VHF radio communications as the bombers assembled over England (7:99-100; 12:177). The SCR-522 VHF Command radio had a bandwidth of 100 to 156 MHz, so this jamming probably also affected the German early warning radars in the same frequency band (7:237; 12:40-41; 17:2). The Americans did not specifically jam the German early warning radars during daylight raids until March 1945 (15:83-92; 18:1-2).

British Tactics

<u>The Bomber Stream</u>. The British built their tactics around the concept of the bomber stream. They intended to saturate the German intercept capability

by having all bombers use the same route, and concentrate their arrival using individual timing. The higher the concentration of the stream, the lower the losses since fewer stragglers were outside of the window corridor that could be quickly intercepted (5:126). The British concentrated the stream into a block 5 NM wide by 17 NM long (20:4). By flying at a variety of altitudes, they could put 30 bombers per minute across the target (5:150; 9:178). A pathfinder force of Lancasters and Mosquitoes marked the bomber route and target with flares to aid the navigation and concentration of the stream. The British stopped route marking early in 1944 since the Germans used the flares to find the bombers. They then concentrated the stream using the H2S radar. However, marking the target continued, with flares being dropped six minutes before the main force arrived (5:127; 9:188-190; 20:3). Whenever the British operated in a single stream it made it easier for the Germans to determine the route and target, so they developed additional tactics (1:99; 9:190).

Spoof Attacks. The British used spoof attacks to divert and dilute the German defenses (9:190, 247; 13:171-172). Spoofs could be countered if they were not realistic enough. This was one of the factors in the outcome of the March 1944 Nuremburg raid where 94 out of 795 bombers were lost. As explained in Chapter 6, the Germans were able to differentiate between the Mosquito and mine laying spoofs, and the real raid (2:78; 13:196-198; 19:123, 125). After the Nuremburg raid, the British started using more complex tactics with small bomber streams attacking several targets at the same time (5:125, 129).

Radar and Communications Jamming. The British used jammers and window to counter the German radars and radio communications. They used ground jammers based in England against the coastal early warning radars and the night fighter communications while the Germans were still in France (14:42; 15:24-25). In late 1943, Bomber Command established No. 100 Group to conduct airborne jamming and night fighter tasks. This unit began effective operations in June 1944. These included Mandrel screens, window spoofs, jamming escort, target support jamming, and fighter escort operations (6:24; 12:176). See Figure 1. Raids started with the activation of the Mandrel screen. This consisted of aircraft that orbited outside German airspace while jamming the early warning radars. The purpose was to prevent the detection of the approaching bomber stream. The main British force approached below 9840 feet to avoid detection as long as possible. Bomber Command directed the crews to restrict their use of the H2S radar until within 50 miles of Germany. They also restricted the use of IFF. Aircraft the Germans detected usually turned out to be spoofing raids until the main bomber stream emerged from the jamming. Window spoofs were small forces that diverged from the main raid while dropping large amounts of window at a high rate. Jamming escorts were a part of the bomber stream and jammed German communications and navigation aids. They sometimes flew above the stream and dropped window so as to appear like another spoofing raid. Target support aircraft jammed the Wurzburg radars at the target (1:201; 5:144; 9:249; 12:176; 13:215, 223-224; 15:35; 20:10, Exhibit K). The British used the Mandrel screen and window spoofs even when there was no real attack so as to increase the stress on the German defenses and prevent the use of these tactics as a valid raid indication (12:176; 15:60). In addition to the above, Mosquito night fighters flew as escorts to protect the stream and also set up ambushes at night fighter beacons and airfields to harass the defenders (1:200-203; 9:247-249; 15:49).

GERMAN TACTICS

Day Fighter Tactics

The purpose of the day tactics was to detect the approaching bombers, and vector the fighters until they could acquire and attack the bomber formations visually (11:35). The radio reconnaissance service monitored the American radio frequencies to determine when a raid was coming and its strength (1:30; 14:82). The fighter controllers used the initial information on a raid to tell which part of Germany the bombers were heading for, and to give the day fighters intercept information (14:49). This information was essential because of the short range and endurance of the day fighters. After takeoff, the controllers acquired and tracked the leader in each fighter formation using IFF and the Y-control system. The Y-station provided the fighter formation's position and information on the bombers to the formation leader (11:35). To fill in the gaps in radar coverage, the Germans used the direction of H2X radar transmissions and the communications between the bombers and escort fighters as ways to determine the position of the raiding force (14:97-98). They also used reconnaissance aircraft flying "contact missions" to provide further information (14:96).

Night Fighter Tactics

Night fighting was a risky mission requiring specialized tactics to be successful. Night fighter losses could occur due to bomber defensive action, British night fighter escorts, friendly flak, malfunctions, weather, and not finding an airfield before running out of gas because the navigation frequencies were jammed (1:111-112). The Germans developed three tactics to control their night fighters. These tactics were known as "Himmelbett", "Wild Boar" and "Tame Boar" (15:220). Once they made contact with the bomber, the night fighters would approach from the rear and then attack from below. This was to avoid the bomber tail gunner and to take advantage of the bomber contrast against the sky (1:15, 41). Due to the fuel shortage that developed in late 1944, the Germans only allowed the best night fighter crews to conduct intercepts. The impact of this was probably lessened since these crews were the only ones who could be successful in the radio and radar jamming environment (1:151, 167, 204).

Like the day tactics, the night tactics depended on an early and correct assessment of the bomber raid to allow the night fighters to be vectored into position in time to complete an intercept (13:172). The Germans needed 40 minutes warning to effectively intercept a bomber force, so they adopted several methods to get this information (9:247). The radio reconnaissance service provided the initial warning based on communication monitoring. After picking up the bomber stream on radar, the Germans vectored a reconnaissance aircraft to intercept and fly with them. This aircraft provided radio reports of the bomber track and altitude, and kept this up throughout the penetration. The primary reason for this was to counter the spoofing raids. The German night fighters also used the route and target marker flares to overcome jamming and follow the bomber stream. The fighter divisions combined this with radar and radio reconnaissance service information to develop an overall picture of the air battle (1:150, 155; 8:224-225; 14:96; 15:220-221).

Himmelbett Tactics. The Germans used Himmelbett tactics, later known as regional night fighting, to intercept isolated aircraft as they tried to penetrate the Kammhuber line. The ground defensive network closely controlled the night fighters with this intercept method (1:57, 202; 10:287; 13:162). This method used a Freya radar for initial raid warning and set-on of Wurzburg tracking. One Wurzburg then tracked the bomber, while another Wurzburg acquired the night fighter at the radio beacon where it was orbiting. The controllers plotted the positions to determine the intercept information given to the fighter (1:57; 15:215-218). This method was susceptible to saturation since only one intercept could be completed for each zone penetrated, and each intercept took about 10 minutes (1:58; 13:104).

Wild Boar Tactics. The Germans used Wild Boar tactics in the target area. It was the most loosely controlled intercept method. The ground controllers projected which city was the target of the raid. They gave this information to day fighters, who went to a beacon to wait for the bombers to arrive (13:146-147). With an efficient early warning system, the day fighters could meet the bombers over any target in Germany due to their high speed (1:62). Once the bombing began, the day fighters flew above the bomber stream and used background illumination from searchlights and fires in the target area, and overhead illumination from flares dropped by other Luftwaffe aircraft, to find the bombers visually and attempt to shoot them down (13:160; 15:218-219).

Tame Boar Tactics. The Germans used Tame Boar tactics to intercept the bomber stream after it penetrated the Kammhuber line and was enroute to the target. This was a hedge to avoid being spoofed and having fighters being sent to the wrong target (5:129). Night fighters were sent to beacons along the route of the bomber stream from the zones that had not been penetrated (1:102). Using the running commentary or the Y-control system, the fighters infiltrated the bomber stream as it passed by (13:173; 15:219-221). They then used their radar to acquire and shoot down bombers as long as their fuel allowed (1:102).

Flak Tactics

The Germans used flak as a point defense. They initially used the flak batteries to defend their cities from the British night bombing. When the Americans began their attacks on industrial targets, the Germans moved the flak to defend them. This concentrated the flak firepower because of the smaller area to defend (11:14). Flak gunners preferred to use optics for angle information but used radar to find the target's range, even in clear weather (12:81). They aimed at the lead aircraft in a formation, and fired all guns in salvoes (12:274). This had to be changed to barrage fire to saturate a sector when the radar and optics were not available. They used information from any available source to determine which sector the bombers were in. This could include sound detectors, unjammed radars, and information from the fighter controllers (11:16-17; 12:170, 274). Barrage fire used ammunition at an unsustainable rate. However, it reduced Allied confidence in their countermeasures even though they were effective (12:169-170).

Chapter Four

THE GERMAN ELECTRONIC ORDER OF BATTLE

The German Electronic Order of Battle (EOB) was developed to find the bomber force and put the defenses in a position to destroy it. See Tables 1 through 3 for the general characteristics of these systems.

AIRBORNE SENSORS

Night Fighter Radars

The Germans developed several families of airborne intercept radars. The radar families that saw extensive service were the various versions of the Lichtenstein and the Neptun. The Germans also developed a higher frequency radar known as the Berlin. However, only 10 of these were produced in time to be used in the war (1:247-250).

Lichtenstein. The twin engine night fighters used the Lichtenstein airborne radar to find the bombers (11:37). The Lichtenstein family of AI radars operated in two frequency bands by the end of the war. This radar had external antennas mounted on the nose of the night fighter. These antennas were large units with the appearance of modern television aerials (15:181). The Germans modified the FuG 202 model to widen its frequency band and it became the model FuG 212. They also improved the angular coverage from 70 degrees to 120 degrees, which made the night fighter less dependent on the ground controller. The disruption of the FuG 202/212 by chaff and jamming led to the development of the FuG 220 Lichtenstein SN-2 which operated in a lower frequency band initially not affected by these countermeasures. The FuG 220 had poor performance when it got within 1640 feet of a bomber so the Germans also installed the FuG 212 to provide close range intercept information. The Germans had deployed the FuG 220 by September 1943 (1:247-248; 15:179-180).

Neptun. The Germans used the Neptun family of radars for airborne intercepts, as well as tail warning of Mosquito attacks. They installed the complex models of the Neptun that could perform both functions on twin engine night fighters. They installed the simpler versions on the single engine fighters used for Wild Boar intercepts. The Neptun worked at a higher frequency than the Lichtenstein SN-2 (1:138, 248-250; 11:37; 15:179-180).

Night Fighter Passive Homers

Radar and Jammer Homers. The Germans used several devices to home on the British jammers, and the Monica and H2S radars. The FuG 227 Flensburg was a passive homing device installed to detect the British Monica tail warning radar used on the Lancaster and Mosquito. The FuG 227 Flensburg-Halbe version could detect the Monica as far as 54 NM away (1:126). It was also used to attempt to home on the Mandrel, Piperack, and Dina II jammers (15:169). The Germans used the FuG 221 Freya-Halbe to home on the jamming of the Freya early warning radar (1:79-80). The FuG 350Z Naxos Z was used to home on the H2S radar, which could be detected up to 27 NM away (1:126).

Infrared Homers. The Germans developed infrared searchlights and detectors for the night fighter to find the bombers. The infrared detectors had relatively poor performance compared to the night fighter radar. They could not detect bombers that had their engine exhausts above the wing or had exhaust flame dampers installed, especially against a background of stars. Their primary utility to the night fighters was to compensate for poor radar detection of the bombers at low altitude (1:39).

GROUND SENSORS

Search Radars

The major German ground radars were the Freya, Mammut, Wassermann, and Jagdschloss. The Freya was an early warning radar with a range of 87 NM (12:277). Window and chaff did not affect it at first because of its low frequency (13:159). The Freya could counter jamming to some extent by changing the radar frequency slightly to get it out from underneath most of the interference (13:129). The Mammut was a more powerful early warning radar with a range of 161 NM (12:277). It used a phased array antenna with a 100 degree wide search pattern, and was difficult to jam (12:275; 13:201). The Wassermann was a height finder radar with electronic scanning to determine the range, azimuth, and height of the bomber (13:69). It was also difficult to jam (13:201). The Jagdschloss was a GCI radar that could show the air situation in a map-like format requiring little interpretation. It had a search range of up to 97 NM, depending on target altitude and the radar model (1:127; 15:185-186). It operated on one of four frequencies that could be selected by the operator (13:216). The Jagdschloss was more powerful than the Freya, and was the best German early warning radar (11:33; 12:276).

Tracking Radars

The Germans used the Wurzburg, Wurzburg-Riese, and Mannheim tracking radars to provide flak fire control, searchlight illumination, and night fighter intercept information (12:28). The Wurzburg could track one target at a time. By the end of the war, this radar operated in the three frequency bands shown in Table 2. Frequencies in bands "A" and "B" could be selected at will. The Germans reserved band "C" for occasions when the other two bands were completely jammed. The Wurzburg-Riese was similar to the Wurzburg except that the Germans increased its antenna size from 10 feet to 25 feet in diameter to improve its range and provide better azimuth and elevation accuracy (12:28, 171). It could withstand jamming better than the smaller Wurzburg (12:281). The Mannheim used the same frequencies as Wurzburg but was more powerful (12:278). The Germans modified the Wurzburg-Riese to add components of the Freya early warning radar to it. This modification was known as the Wurzburg-Riese-Gustav. This allowed the radar crew to obtain range from the unjammed frequency used by the Freya component when the Wurzburg was jammed. Angle information was obtained by attempting to DF the jamming using the Wurzburg component (12:276, 279).

The Wurzburg had several electronic counter-countermeasure (ECCM) techniques to allow it to operate despite Allied chaff and jamming. However, the ECCM only worked for small amounts of chaff (12:83). The Wurzlaus ECCM technique used the doppler effect to cancel the effects of window and chaff. This was effective unless the chaff was dense or the wind was blowing faster than 22 knots. Wurzlaus reduced the range of the Wurzburg and was complicated to use (1:122; 12:284). The Nurnberg ECCM technique used propeller modulation effects to differentiate between chaff/window and the real aircraft. The Germans used it to aid the Wurzlaus technique when the chaff was dense (1:122; 12:284-285). The Wismar ECCM allowed the Wurzburg to change frequencies to avoid jamming. Changing frequencies within a band took one minute. Changing frequencies between bands took four minutes. Use of Wismar made the Wurzlaus technique ineffective (12:101, 285-286).

Passive Detection

The radio reconnaissance service monitored Allied radio, navigation, and radar equipment to tell when a raid was coming, and to tell the route of flight (14:82). The Germans used the Naxburg, a Naxos Z hooked up to a Wurzburg antenna, to provide precise direction finding of the British H2S radar. They also used the Korfu to detect the H2S, as well as the American H2X radar (1:247, 252; 13:176; 15:192). The Germans also obtained the location of the bombers by triggering their IFF (13:176).

COMMAND AND CONTROL

German IFF

The Germans used the FuG 25a Erstling IFF to determine where their fighters were, and to tell them apart from the attacking bombers. The FuG 25a only responded to radars operating in the same frequency range as the Freya (1:253; 15:195). The fighter control service also used Y-stations and Freya-Egon systems to keep track of the location of the fighters. There were five Y-stations and 3 Freya-Egons for each radar (11:35).

Radio Communications

The Germans used VHF and HF radio communications so the controllers could direct the fighters, and so the fighters could pass information to other fighters and their controllers. They used the FuG 10 for HF communications with the night fighters (15:194). The Germans attempted to counter HF communications jamming by increasing the power of their radio transmitters. Later they started using the VHF radio band for night fighting, as well as to control the day fighters (13:130). The FuG 16 VHF radio had a frequency band of approximately 38 to 43 MHz (12:40). In further attempts to avoid jamming, the Germans used the "Anna Marie" radio station in Stuttgart operating at a frequency of 300 KHz to indicate the general location of the bombers by the type of music being played (6:24; 9:189; 10:387; 15:157).

Navigation and Control Systems

The German fighters used the HF and VHF radios for navigation and control functions where possible. The German Y-control system, also known as "Benito", used the FuG 16 VHF radio as a method for a ground controller to determine the position of a fighter, while the fighter could use the same frequency to talk to other fighters or receive the " . . . running commentary on the position, course, and altitude of enemy formations" (15:154, 199). This method worked by transmitting a calibration signal to the fighter. The fighter automatically re-transmitted the signal to the ground. The time difference indicated the range, while ground DF antennas indicated the direction of the fighter (1:76-77). The Bernhardine set received and printed running commentary and navigation information from the Bernhard ground station. The night fighters also got navigation information by using the DF capability of the HF and VHF radios (1:246-247).

Chapter Five

ALLIED ELECTRONIC COMBAT EQUIPMENT

The Allies had code names to designate the families of jammers developed to counter specific radars. For example, "Mandrel" was the code name for the jammers used to counter the Freya early warning radar. American and British jammers with the same code name had little in common beyond the radar they were targeted against (12:27, 59). Tables 4 through 6 list the jammers used by the Americans and British. Table 7 has the characteristics of the chaff and window.

AMERICAN ELECTRONIC COMBAT EQUIPMENT

American Radar Jammers

Search Radar Jamming. The Americans developed search radar jammers, but used them on a limited basis. The APT-1 Dina was a modification of the APT-3 Mandrel to increase its frequency range. The Americans apparently did not install it in regular unit bombers. The 36th BMS used both of these jammers for VHF radio and radar screening operations during the early part of a daylight raid, and to support the British Mandrel screen during night operations (7:99-100, 242).

Tracking Radar Jamming. The Americans used the APT-2 Carpet I to jam the Wurzburg (7:242; 12:45). Due to the initial shortage of Carpets, they only installed one in each B-17. Each Carpet could only cover about 2 MHz, so the entire combat box had to be used to jam the Wurzburg frequency band (12:82, 102-104). The Americans used specially modified aircraft to monitor the Wurzburg frequencies. They then used the frequency distribution to tune the jammers for the next mission (12:102). Delivery problems continued to prevent large-scale use of Carpet until October 1944 (12:83, 167). Due to this shortage, and the reduced number of aircraft in the bomber box, the Americans had to use Carpets that could be manually tuned in flight to jam the new Wurzburg "B" band in the summer of 1944 (12:105-106). This modification was known as the APQ-9 Carpet III (7:97). Once they alleviated the shortage, the Americans increased the number of Carpets to two per aircraft (7:97). At this point, they barrage jammed the "A" and "B" bands with preset tuned jammers. Operators manually jammed the Wurzburg "C" band when it appeared (12:172).

American Communications Jammers

The Americans developed communications jammers but did not want to use them during bombing missions because of the intelligence information they could obtain from the German radio traffic (12:43, 175). An exception to this occurred when 8th Air Force attempted some voice deception jamming on the German Y-control frequencies (7:98). As discussed previously, 8th Air Force also used APT-3 Mandrel jammers installed on 36th BMS aircraft to jam the American SCR-522 VHF radio to prevent monitoring by the Germans (7:99, 242).

American Chaff

The Americans used CHA-3 and CHA-28 chaff to counter the Wurzburg class of tracking radars. They apparently did not drop chaff to affect radars operating in the Freya frequency band (7:98, 201; 12:83). The Americans increased the use of chaff until in October 1944 " . . . consumption by the 8th Air Force alone, was running at about 1,000 tons per month" (12:168).

BRITISH ELECTRONIC COMBAT EQUIPMENT

British Radar Jammers

Search Radar Jammers. The British used the Mandrel and Moonshine to jam the Freya, Mammut, Wassermann, and Jagdschloss early warning radars. The No. 100 Group had Mandrels installed for 88 to 148 MHz (barrage), and 148 to 200 MHz (spot). They also modified the American Mandrel so it could be used in the Mandrel Screen. The Mandrels used by the main force bombers could only cover from 118 to 148 MHz. The British tuned all jammers in a main force squadron to the same 10 MHz wide band. The jammers periodically stopped transmitting for two minutes to prevent homing (13:129; 15:154, 160). The Moonshine jammer amplified the radar return of the jamming aircraft and made it appear as big as a bomber formation to the early warning radars. The aircraft acted as part of a spoofing force to draw the Germans away from the real bombers. Each Moonshine could jam one radar at a time (12:37-39).

Tracking Radar Jammers. The British used the Carpet II jammer to jam the Wurzburg. They apparently only installed these jammers on selected aircraft (15:156). Throughout the war, the British bomber crews thought they could counter the Wurzburg by jamming it with their IFF sets. This led to the development of a switch which made the IFF radiate continuously. This jammer was known as Shiver (13:92-93; 15:160).

Airborne Intercept Radar Jammers. The British had to continually expand their frequency coverage against the AI radars. They used the Ground Grocer ground based jammer to jam the early Lichtenstein (15:158). They used the Dina II and Piperack jammers against the new frequencies used by the Lichtenstein SN-2 (13:224, 239). They needed six Piperack jammers to cover all the Lichtenstein SN-2 frequencies (15:103).

British Communications Jammers

The British had to develop a wide range of jammers to counter the German efforts to communicate with their night fighters. Besides the HF and VHF jammers, the British used the Dartboard jammer to interfere with the German radio station operating on 300 KHz (15:157).

HF Jammers. The British used airborne and ground HF jammers. They used Tinsel to jam HF voice communications (12:59). Drumstick jammed Morse code signals used to control the night fighter force (1:152; 13:188-189; 15:157). Corona was a ground HF jammer used to broadcast false information to the German night fighters or attempt to tie up their communications channel (13:182-184). The Germans attempted to counter these jammers by changing frequencies during intercepts and by using the VHF frequency band (15:25).

VHF Jammers. The British installed most of their VHF jammers in aircraft. Special Tinsel was the first VHF jammer, but the Germans overcame it with the higher power FuG 16 VHF transmitter and by using several frequencies simultaneously (13:182, 186-187). The British then used the Airborne Cigar (ABC) jammer to counter the German VHF communications and navigation aid frequencies. An operator monitored the German communications to make sure all frequencies were jammed (13:181; 15:153-154). Three frequencies could be jammed at the same time (15:153-154). The British also used a modified Airborne Cigar to jam 31.2 MHz and the Y-control system (15:45, 153-154). The Jostle IV VHF jammer replaced the Airborne Cigar. It radiated 2000 watts which covered the entire radio band rather than jamming just one frequency at a time. Jamming was applied for one minute followed by a 15 second break to prevent the Germans from homing on the transmissions. Jostle IV prevented the Germans from using the VHF band (13:222-223; 15:144-145). Jostle IV was first used on 30 June 1944 (15:61).

British Passive and Active Detectors

In addition to AI radar, the British developed equipment for their Mosquitoes to home on the German night fighters. The Perfectos allowed homing on the German night fighter's FuG 25a IFF (13:220; 15:64. 167). The Germans countered this by turning off their IFF, which meant the ground controllers could not tell friend from foe (13:220). The Serrate allowed homing on the German night fighter radar. It had to be modified in the summer of 1944 to allow it to pick up the Lichtenstein SN-2 (13:220).

The British used the Monica tail warning radar to notify the Lancaster or Mosquito crew of night fighter attacks. Monica had a 45 degree wide zone of coverage and a range of 1000 yards. The British removed it in the summer of 1944 when they discovered the Germans could home on it (13:139, 214-215).

British Window

The British did not use window until July 1943 to keep the Germans from finding out about it (10:289, 299). Initially, it only affected radars operating above 200 MHz (15:21). The British had to widen the frequency coverage several times to match the expanding frequency bands of the German radars. The British first used Type MB window to support bomber operations the night of 23 July 1944. This chaff could counter radars operating from 60 to 200 MHz, such as the Freya and the Lichtenstein SN-2 (15:61). They later used a combination of Type MM and Type N3 window for spoof raids to counter low and high frequency radars (20:K-2 - K-4).

Chapter Six

THE EFFECTIVENESS OF ALLIED ELECTRONIC COMBAT

The author determined the effectiveness of the electronic combat in this conflict using a qualitative assessment of its effects. This was because of the lack of information to perform a quantitative assessment, such as using the jamming-to-signal ratio available for the various jammers (4:83-85). The effectiveness varied with the cycle of moves and countermoves by each side. Factors such as this have been correlated in the following assessment.

ALLIED RADAR JAMMING

Search Radar Jamming

The jamming of German search radars by the British Mandrel screen and main force bombers was generally effective. The Americans did not jam these radars until March 1945, except as a by-product of their VHF radio screening. The British had to constantly expand the Mandrel frequency coverage to counter the capability of radars in the Freya band (12:59). As a result of the "Post Mortem" exercise conducted after the war, the British found that the jamming against the Freya and Mammut radars was very effective. However, in the case of the Wassermann and Jagdschloss radars, the Germans could find usable frequencies if jamming was conducted without dropping window as well. This was probably due to inadequate jammer and window coverage at the low and high early warning radar frequencies, as can be seen in Figure 4 (15:113-120, 123).

Track Radar Jamming

The Americans could not completely counter the Wurzburg class of radars with jamming even after large numbers of Carpet jammers became available. This was because of the small jammer spot widths and resulting inadequate frequency coverage of the Wurzburg bands, especially the "C" band which could not be barrage jammed. This allowed the Wurzburg operators to tune away from Carpet jamming to at least temporarily find a clear frequency (12:287).

Night Fighter Radar Jamming

The British used the Ground Grocer jammer based in England to jam the early Lichtenstein, the main purpose being to reduce its effective range. They probably also used the Carpet II to jam the Lichtenstein C-1 (15:156, 158). The British used the Piperack jammer to counter the Lichtenstein SN-2 in September 1944. This jamming was very effective (13:239).

ALLIED CHAFF/WINDOW

The Allies successfully degraded the German defensive network when they used chaff and window. The Americans only used chaff to counter track radars. The British used window to counter search radars, track radars, and AI radars. The use of window in July 1943 exposed a German weakness where the early Lichtenstein and Wurzburg used the same frequency band and could be simultaneously nullified. The loss of both of these radars at the same time temporarily devastated the German defenses (2:72-74; 13:151-159). They recovered by relying more on unaffected systems. Window hid individual aircraft, but the search and tracking radars could use it to determine the track of the bomber stream. In addition, the window/chaff did not prevent radars from tracking the lead aircraft (1:96; 12:188; 13:243; 15:123). The night fighters could tell the bomber from the chaff by the rate of movement on their radar displays (13:157). The early window did not affect low frequency radars, and the night fighters eventually resumed normal operations with the Lichtenstein SN-2 and the Neptun. The SN-2 was not countered by low frequency response window until July 1944 (13:192, 214; 15:61).

ALLIED COMMUNICATIONS JAMMING

The effectiveness of Allied communications jamming varied depending on a variety of circumstances, but generally it made the control of night fighters difficult.

> Only by broadcasting their orders simultaneously on a number of channels could the German fighter controllers avoid the worst effects of this jamming barrage. This in turn meant that the frustrated aircrews had their work cut out searching the spectrum for unjammed frequencies, and even when these were found there was no guarantee that they would remain that way for long. By the beginning of 1944 the combined [HF and VHF radio] offensive mounted by the "Tinsel", "Corona", "Airborne Cigar", "Drumstick" and "Dartboard" jammers had brought chaos to German night-fighter communications (13:189).

Jamming made control of the night fighter force very difficult, but the British were not able to simultaneously stop all means of communication (8:223; 14:85). The night fighters would not lose the bombers until the communications and Y-control system were jammed simultaneously (1:150, 159). The British tactic of interrupting the communications jamming to prevent homing allowed the night fighters to get information from the running commentary (15:141). With the introduction of the Jostle IV jammer, the Germans eventually had to abandon the VHF radio band and go back to using only the HF frequencies (13:222-223; 15:144-145).

ALLIED EMISSION CONTROL MEASURES

Despite emission control, the German radio reconnaissance service could consistently locate the bombers. They could predict the night of a British raid by the amount of radio test traffic the morning prior (13:153-154). They also got warning of raids when the British switched on the radio beams used by the Gee navigation system (13:183, 188). As mentioned previously, they also continued to determine the track of the bombers using the H2S/H2X radars, IFF, and radios.

The British countered the Naxos and Freya-Halbe with mixed results. Cutting down the use of the H2S was very effective in preventing intercepts by the night fighters (1:167). In early 1945, the Naxos was the only unjammed method the night fighters had to find the bombers, but intercepts became easier because the bomber crews were not restricting the use of the H2S as much (1:181, 207). The British periodically shut off jamming of the Freya, but the effectiveness of this could not be determined since the Freya-Halbe did not work very well (15:168).

ALLIED TACTICS

The tactics used by the Allies gave mixed results. The American tactics were probably oriented toward allowing the German day fighters to operate so they could be engaged by American escort fighters. The British encountered a problem with the concept of the bomber stream. The better the concentration, the harder it became for the Germans to find and shoot down stragglers. But at the same time, it became easier for the night fighters to find the bomber stream, due to H2S transmissions, route markers, and target marking (5:127-128). The Germans were vulnerable to spoofing raids on false targets, but this required large raids to appear convincing (5:128). In addition, the Germans could tell the difference between Mosquito spoofing attacks and real raids because the Mosquito was not equipped with H2S, and because of its higher speed (13:183, 188, 196). As demonstrated in the Post Mortem exercise, the use of the low level approach was a major contributor to compressing the time available to the Germans for responding to an attack (15:123).

COMBINATION EFFECTS

Radar and Communications Jamming

British losses initially declined by one third after communications and early warning radar jamming (Tinsel/Mandrel) started in December 1942. The Germans recovered from this without too much difficulty, probably because they could still depend on the Wurzburg and Lichtenstein radars (12:59).

Jamming and Passive Detection

Jamming could be negated by the radio reconnaissance service if electromagnetic sources were available in the bomber stream such as H2S and IFF. This was partially alleviated by orders to reduce these emissions (15:124, 139). The Post Mortem exercise showed that the Mandrel screen, used to reduce the warning time of an attack, was not always effective because the radio reconnaissance service could always intercept IFF or H2S and tell the location of the bomber stream (15:118-121).

Jamming and Chaff/Window

Tracking Radars. The Germans encountered major problems when chaff was used against the Wurzburg in conjunction with jamming. A frequency change to get away from the jamming made the chaff ECCM ineffective since this required retuning the radar (12:101, 284-285). The Germans considered the American jamming of Wurzburg more effective than the British jamming which did not saturate the Wurzburg (12:280). Even though their radars were severely affected by the jamming and chaff, the Germans could still inflict heavy flak losses when they had enough information and ammunition to use barrage fire. The flak was also still able to shoot down some bombers because radar operators could sometimes find unjammed frequencies, wind would blow the chaff away, and because of the closeness of the bomber formations (12:169-171).

Search Radars. In the Post Mortem exercise, the British found that the feints and spoofing raids used in conjunction with window and jamming were effective in confusing the defenses (13:241-242; 15:122-124). The Wurzburg, Freya, Mammut, and Jagdschloss were usually effectively jammed when both jamming and window were used. The Wassermann radar was resistant but still affected (15:137-138). The radars were probably resistant because of the unjammed frequencies that could be used, as can be seen in Figure 4.

Night Fighter Radars. Window affected the Lichtenstein SN-2 radar but it could still change frequencies to allow limited operations (15:139-140). In addition, it could be used by the night fighter to infiltrate the bomber stream and follow the chaff trails to the lead bombers. It was finally countered with the Piperack jammer, in combination with chaff with the right frequency response, in September 1944 (1:177). This left the FuG 218 Neptun radar and the FuG 350 Naxos as the only means the night fighter had to find the bomber stream (1:178, 181). The Neptun was eventually defeated using the Mandrel IV and Type M series window (15:139-140, 160-163).

Visual Acquisition

There were constant recurrences of large bomber streams making it through unscathed, until the last wave hit the target. In several cases the only reason any intercepts occurred at all was that the night fighters noticed the large fires that started when the first wave of bombers attacked the real target. These fires could be seen as far as 60 miles away at night. There was also the ability of reconnaissance aircraft to follow and report on the bombers when jamming shut off all radar information (1:141-155; 8:225; 15:122). Apparently, the key in these cases was that the aircraft could communicate their findings to the night fighters or to the fighter division.

Mosquito Night Fighter Escorts

The Mosquitoes were a disappointment to the British because of the low number of German night fighters shot down (5:145-150; 10:399). However, they were enough to make the Germans turn off their IFF sets. This resulted in the loss of any ability for the German controllers to vector their night fighters, or even to tell friendly from enemy radar tracks (1:202; 13:238-239). They also caused a near panic in the German night fighter force (1:200-204).

Chapter Seven

EFFECTIVENESS FACTORS

GERMAN LOSS OF THE INITIATIVE

Allied technical innovation proved decisive in determining the outcome of each swing of countermeasures applications. This was because the German hierarchy did not realize the importance of radar and electronics until it was too late. In addition, the " . . . research establishments and the industry had no idea of what the fighting units really required . . ." (1:74-75). They froze their research efforts too early in order to focus on near-term problems. When their defenses became saturated with jamming and chaff, they attempted to develop higher frequency ground and AI radars, but this came too late to be of any operational use (1:180-182). On the other hand, the Allies had a development effort that could quickly find a counter to German initiatives. An exception to this was the nine months it took the British to find out about the new frequencies used by the Lichtenstein SN-2, as well as the German use of the Flensburg and Naxos. Once countermeasures were applied, it severely affected the night fighters, and the Germans never recovered.

MASS EFFECTS

There appeared to be two opposing results of the large number of bombers massed for a raid. The first was that jamming was made easier because of the large numbers of aircraft involved. They made up for the low power of the jammers and the uneven distribution of chaff dispensed by hand (12:254). This also compensated for the jammers that frequently malfunctioned, and the equipment that was difficult to operate (15:138). It also allowed chaff drops to cover the following aircraft. Finally, the large numbers could saturate the defenses if they were not built in depth. Opposed to this was the fact that the large size of the bomber streams and formations made them easier to find amongst the jamming, chaff, and spoofing raids. Once a night fighter made it to the general vicinity of the stream, any inaccuracies in the running commentary became irrelevant as any bomber would do for the fighter to complete an intercept. It also made it easier for the flak defenses since a shell that missed one bomber could hit another (6:22). The size of the bomber stream meant there was a prolonged period of time required to bomb the target. This allowed tactics that concentrated the fighters where the bombers could be readily found. Finally, the concentration of a large number of bombers equipped with radar and IFF meant the German radio reconnaissance service could find their general position even when crews were practicing good emission control procedures on an individual basis. Even though individual

H2S or H2X radars were on for a short period, the cumulative effect was probably a continuous source of DF information. Finally, the unfortunate belief that the Wurzburg type of tracking radars could be countered with the IFF or Shiver jammer meant there was another continuous source of DF information.

CUTTING MULTIPLE LINKS

Electronic combat has been compared to breaking a link in a chain to prevent a successful engagement (12:254). However, the German defense system was not tied together with simple links that could be cut in one place so that everything fell apart. As shown in Figures 2 and 3, each link had multiple parts, with some parts stronger than others. The German defenses were " . . . flexible enough to overcome the worst effects of jamming by the use of whichever element was least affected at any given time" (15:139). Under the strain of combat, the weaker parts could be made to give way due to the stress. The parts relationships and strengths changed throughout the war under the stress of Allied actions. When this occurred, the loss rate " . . . closely corresponded to the introduction of new measures and counter-measures by both sides favouring [sic] now the night bombers and now the night fighters" (5:126). Technological advances, new tactics, loss of territory, fuel shortages, and destruction influenced whether a part would stand up, fail, or gain new life. The pace of combat allowed the Germans to recover and come up with alternatives. The most effective denial was achieved when several links were hit at once, denying the option to work around the problem. The Allied tactics became more and more successful as each link used by the Germans to control their forces was denied to them.

Tracking Radar Jamming

The Americans concentrated their efforts against the tracking radars, such as the Wurzburg. Jamming and chaff together was effective because if the radar was able to find an unjammed frequency it still had to contend with the chaff. Jamming of the early warning radars was almost ignored. This allowed the flak units to obtain information for barrage firing from the early warning radars and fighter controllers, as well as from the radio reconnaissance service. The British depended on window and jammers outside the target area for jamming the Wurzburg. While providing less effective protection from the Wurzburg, there may have been better overall protection from barrage firing because the early warning radars were also being jammed.

Search Radar and Communications Jamming

The Americans allowed the early warning radars and fighter communications to operate almost unhindered, while the British effectively countered both. Jamming the search radars raised the importance of communications as a workaround. The British communications jamming prevented passing of information from German observer and fighter aircraft of spoofs, bomber force size, and location. However, the large number of communications links made this very difficult. The British eventually negated the effectiveness of the night fighter force, so that only the best crews could operate at all.

Mosquito Night Escort Fighters

The loss of IFF information caused by the Mosquitoes kept the German controllers from determining where there fighters were. This prevented the fighters from being wielded as an effective force, and probably led to losses caused by friendly flak and night fighters (1:202; 13:220).

Emission Control

The German controllers could determine the location and route of the bomber stream because of IFF and radar transmissions, even when the early warning radars were jammed. The large numbers of bombers equipped with radar made it certain that emissions could always be detected, even when individual radars were only on for a short time. The concentration of the formations meant all DF information was useful in determining the location of the bombers. Given the ineffectiveness of the H2S radar and IFF emission controls, the automatic shutdown of jammers to prevent homing probably did more harm than good, especially for the relatively small number of aircraft equipped with communications jammers (20:Exhibit X).

Incomplete Frequency Coverage

The Allies did not have adequate jamming transmitters to counter signals throughout the frequency spectrum. This allowed some of the German early warning radars to escape the Allied jamming by changing their operating frequencies.

Chapter Eight

SUMMARY

FINDINGS

The Germans had a complex air defense system that the Allies defeated after a prolonged series of measures and countermeasures. Window, chaff, Mandrel, Tinsel, Airborne Cigar, Piperack, and Carpet provided definite advantages as the Allies introduced them into the conflict, and provided temporary decreases in loss rates to make up for the long exposure of the bombers to radar, flak, and fighters. These gains were temporary because the pace of conflict allowed the Germans time to develop new tactics or equipment to make up for each countermeasure. However, eventually the Germans ran out of options. This occurred in the late summer of 1944 when several factors almost simultaneously shut down the German defensive effort. During this time the Germans lost the use of the early warning radars in France. This allowed the British to approach Germany at a lower altitude and reduced the warning time of a raid. The British also changed their tactics to increase the number of spoofing raids. The Allied bombing effort had reduced the fuel available for the fighter force. These factors put additional strain on the German defenses. The Americans finally had enough jammers to protect their bombers from flak. The British finally were able to defeat most of the night fighter and flak radars when they got jammers with sufficient frequency coverage. The Mosquito night fighters forced the Germans to turn off their IFF. In essence, the Allies were able to cut or disrupt all of the links in the German defensive network and render it ineffective.

CONCLUSIONS

While temporary advantages occurred as the Allies introduced various countermeasures, it was not until they cut several links simultaneously that the Germans lost the air battle. In the case of the night fighters, the British then kept the pressure on so that the Germans could not work around the countermeasures. In the case of the daylight raids, the American jamming and chaff increased the ammunition cost to the Germans, but it did not cut the links required to defeat the flak battery's last option, barrage firing.

RECOMMENDATION

Recommend the project sponsor incorporate this study into the Strategic Air Command historical data base.

System & Nomenclature	Function	Frequency Band (MHz)	Max Range (NM)	Power (watts)	Source
FuG 202 Lichtenstein BC	AI Radar	490	[1.8]	1500	1:247 15:179
FuG 212 Lichtenstein C-1	AI Radar	420 - 480	[1.0]	-	1:247 15:179
FuG 216/217/218 Neptun R	Tail Warning Radar	182 (typical)	-	1000	1:248-250 15:179-180
FuG 216/217/218 Neptun V or J	AI Radar	125 (typical)	[1.9]	1200	1:249-250 15:179-180
FuG 218 Neptun V/R	AI and Tail Warning Radar	158 - 187	-	2000	1:178,250 15:180
FuG 220 Lichtenstein SN-2	AI Radar	37.5 - 118	[2.2]	2500	1:248 15:180
FuG 221 Freya-Halbe	Passive Homer (Mandrel)	115 - 135	[54.3]	N/A	1:251 15:168
FuG 227 Flensburg	Passive Homer (Monica)	80 - 230	[54.3]	N/A	1:251 15:169
FuG 240 Berlin	AI Radar	3250 - 3330	[2.7]	-	1:250 15:180
FuG 280 Kiel Z	Passive Homer	Infrared	[2.2]	N/A	1:247 15:170
FuG 350 Naxos Z	Passive Homer (H2S)	2500 - 3750	[27.1]	N/A	1:252 15:169

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. Brackets [xxx] indicate values converted from another measurement system, i.e. wavelength to frequency. Underlined numbers (xxx) indicate a conflict among the references, with the most reasonable value presented here. A dash (-) indicates information that was not available.

Table 1. German Electronic Order of Battle (Airborne Sensors)

System & Nomenclature	Function	Frequency Band (MHz)	Max Range (NM)	Power (kW)	Source
[FuMG] 51 Mammut	EW Radar	120 - 150	[161]	200	1:254 12:277 15:186
FuMG 62 Wurzburg	GCI & Fire Control Radar	440 - 470 (C) 517 - 529 (B) 553 - 566 (A)	[13 - 22]	7-11	12:278 15:188-190
FuMG 65 Wurzburg-Riese	GCI & Fire Control Radar	517 - 529 (B) 553 - 566 (A)	[19 - 32]	7-11	1:256 12:279 15:190-192
FuMG 80 Freya	EW Radar	57 - 250	[87]	15-20	1:255 12:277 15:183-185
FuMG 402 Wassermann	EW & HF Radar	75 - 250	[152]	100	1:254 12:277 15:187-188
FuMG 404 Jagdschloss	GCI Radar	129 - 250	[97]	150	1:256 12:277 15:185-186
Korfu	Passive DF (H2S/H2X)	[3600] [10,000]	[87]	N/A	1:252 15:170,192
Naxburg	Passive DF (H2S)	2500 - 3750	[87]	N/A	1:247,252 15:169,192

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. Brackets [xxx] indicate values converted from another measurement system, i.e. wavelength to frequency. Underlined numbers (xxx) indicate a conflict among the references, with the most reasonable value presented here.

Table 2. German Electronic Order of Battle (Ground Sensors)

System & Nomenclature	Function	Frequency Band (MHz)	Max Range (NM)	Power (watts)	Source
FuG 10	Radio Communications & DF Navigation	0.3 - 0.6 3 - 6	-	-	1:246 15:194
FuG 10K (K3)	Radio Communications & DF Navigation	6 - 18	-	-	15:194
FuG 16ZY	Radio Communications, Y-control, & Navigation	38.5 - 42.3	-	-	1:246 15:195
FuG 16ZS	Radio Communications	40 - 45	-	-	15:195
FuG 25a Erstling	IFF	Rx 123 - 128 Tx 150 - 160	[145]	8000 1500	1:253 15:195
FuG 120 Bernadine	Radio Teletype & Navigation	30 - 33.3	[215]	-	1:246 15:195-197
FuG 125 Hermine	Navigation	30 - 33.3	[108]	-	1:247

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. Brackets [xxx] indicate values converted from another measurement system, i.e. wavelength to frequency. Underlined numbers (xxx) indicate a conflict among the references, with the most reasonable value presented here. A dash (-) indicates information that was not available.

Table 3. German Electronic Order of Battle (Command & Control)

System	Frequency Band (MHz)	Spot Width (MHz)	Power (watts)	Source
APT-1 Dina II	90 - 220	-	12	12:272 15:157
APT-2 Carpet	450 - 720	2	5	12:103,272
APT-3 Mandrel	85 - 135	10	100	12:272 15:154
APT-5 Carpet IV	350 - 1200	-	15	12:272
APQ-2 Rug	450 - 720	-	5	12:272
APQ-9 Carpet III	475 - 585	-	20	12:272 15:157

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. A dash (-) indicates information that was not available. Underlined numbers (xxx) indicate a conflict among the references, with the most reasonable value presented here.

3. As with the British jammers contained in Table 5, the above systems may have had several transmitter sub-bands that collectively give the frequency bands shown.

Table 4. American Airborne Jammers

System	Frequency Band (MHz)	Spot Width (MHz)	Power (watts)	Source
Airborne Cigar	38.3 - 42.5 30.0 - 33.0 48.0 - 52.0	-	50	15:154
American Mandrel	63 - 103 92 - 133 143 - 203	10	2	15:154,156
Carpet II	300 - 600	-	-	15:156
Jostle IV	3 - 6 6 - 12 12 - 18 26 - 35 35 - 45 45 - 54	-	2000	15:159 13:222-223
Mandrel I	88 - 98 98 - 108 108 - 118 118 - 128 128 - 138 138 - 148	10	1200	15:160
Mandrel III	29 - 39 148 - 196	-	-	15:160
Mandrel IV	148 - 200	-	-	15:160
Moonshine	-	-	-	15:160
Piperack	69 - 93	-	-	15:98,160
Shiver	24 - 26	-	-	15:160-161
Special Tinsel	38 - 42	-	-	13:172-173
Tinsel	3 - 6	-	-	15:161

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. A dash (-) indicates information that was not available.

Table 5. British Airborne Jammers

System	Frequency Band (MHz)	Spot Width (MHz)	Power (watts)	Source
Corona	2.5 - 6	-	-	15:24,157
Dartboard	0.3	-	-	15:45,157
Drumstick	3 - 6	-	-	15:157-158
Ground Cigar	38 - 42	-	-	15:158
Ground Grocer	480 - 500	-	-	15:158
Ground Mandrel	90 - 200	-	-	15:158

Notes

1. Only systems with significant usage are included here. Data has been extracted and collated from the references shown in the source column.

2. A dash (-) indicates information that was not available.

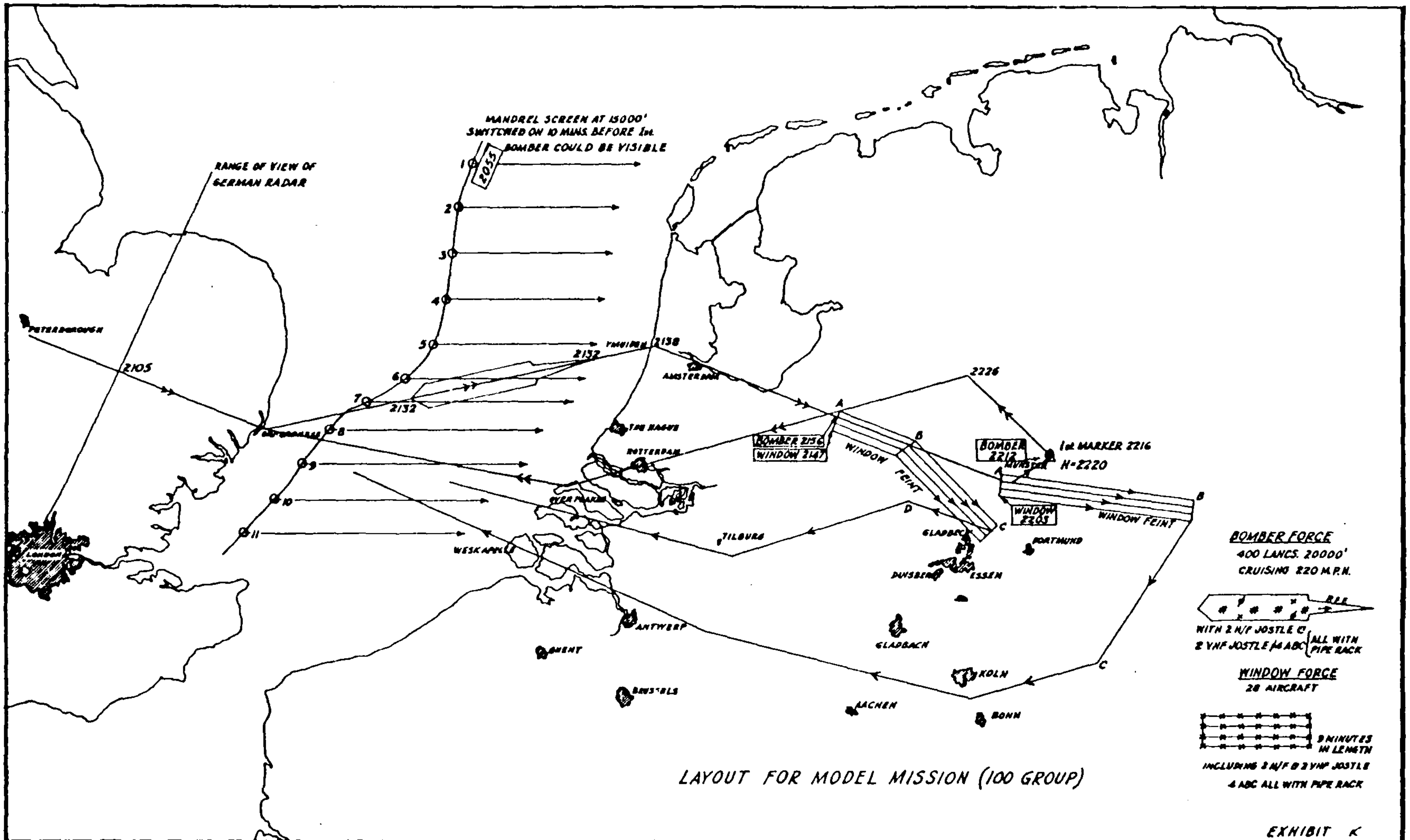
Table 6. British Ground Jammers

	Nomenclature	Frequencies Affected (MHz)	Source
American Chaff	CHA-2	347 - 404	12:273
	CHA-3	510 - 595	
	CHA-25	320 - 600	
	CHA-28	450 - 600	
	CHB-0	110 - 116	
British Window	Type A, C, E, F, F3	450 - 500	15:162-163
	Type N, N3	350 - 600	
	Type MB	70 - 200	
	Type MC, MC2	85 - 100 140 - 200	
	Type MD2	65 - 100 140 - 200	
	Type MM	65 - 200	

Note

Only chaff or Window with significant usage is included here. Data has been extracted and collated from the references shown in the source column.

Table 7. American Chaff and British Window



Note: Reprinted from Description of R.A.F. Bombing, USSBS Vol 64, January 1947.

Figure 1. Layout For Model Mission (100 Group)

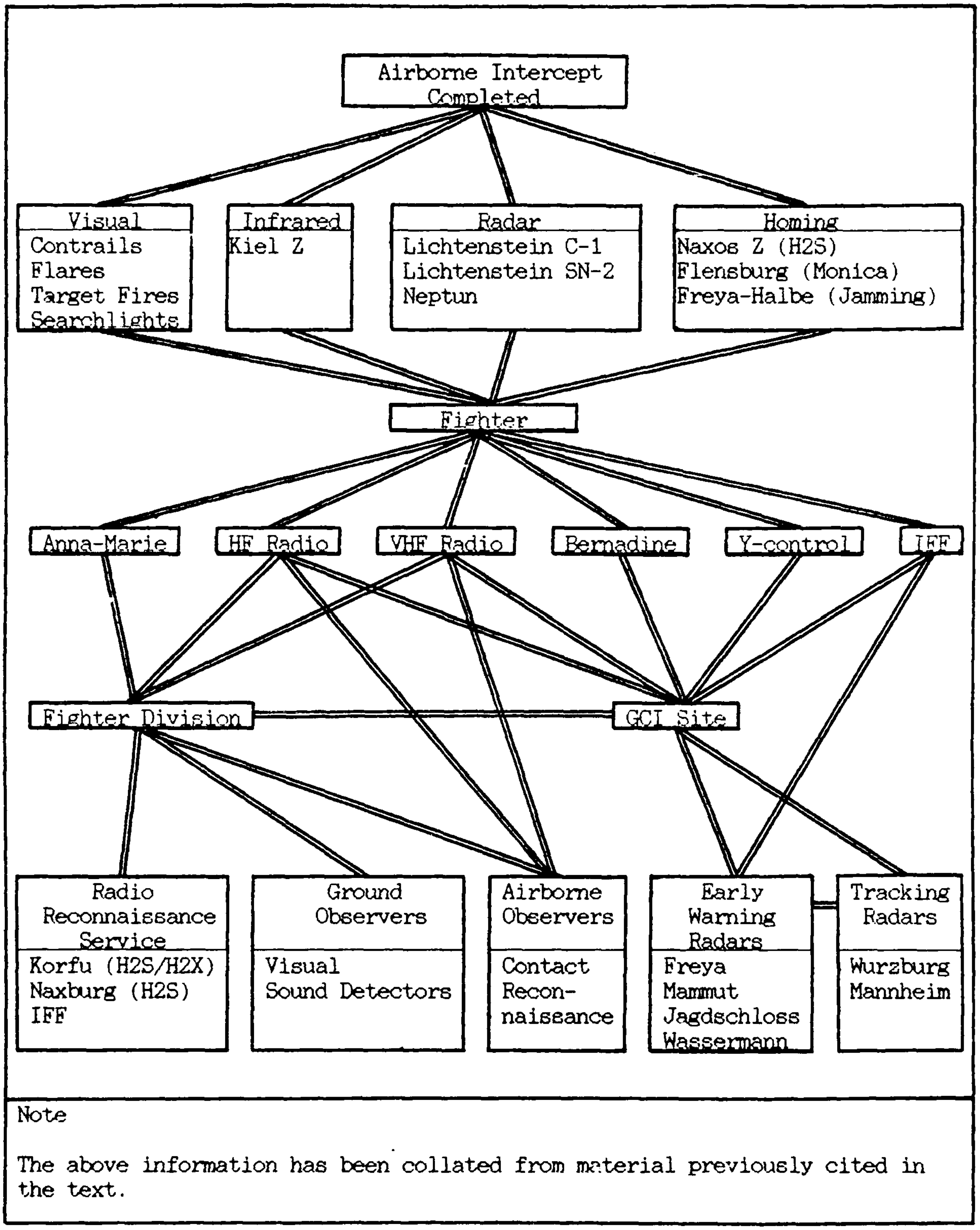
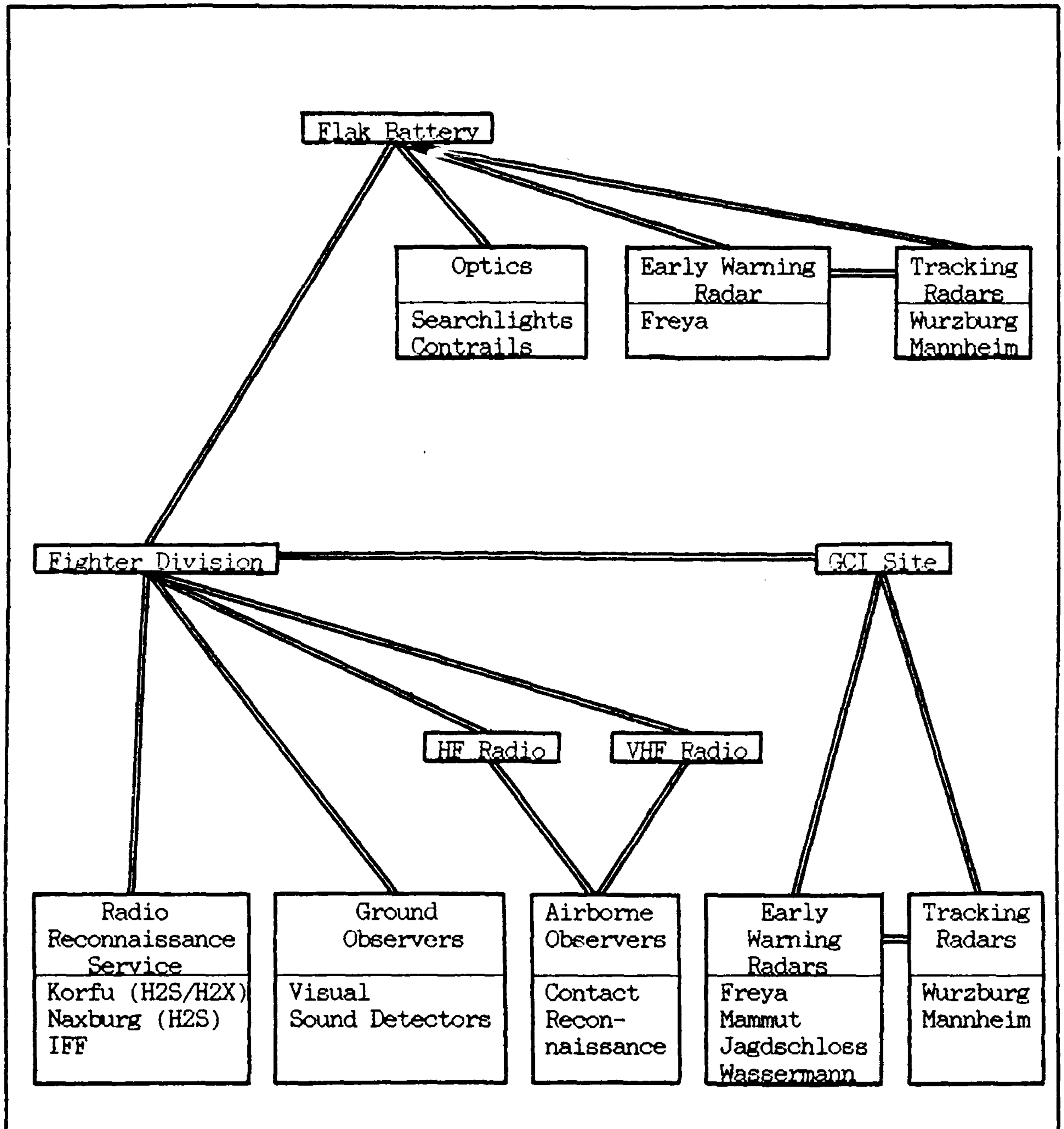


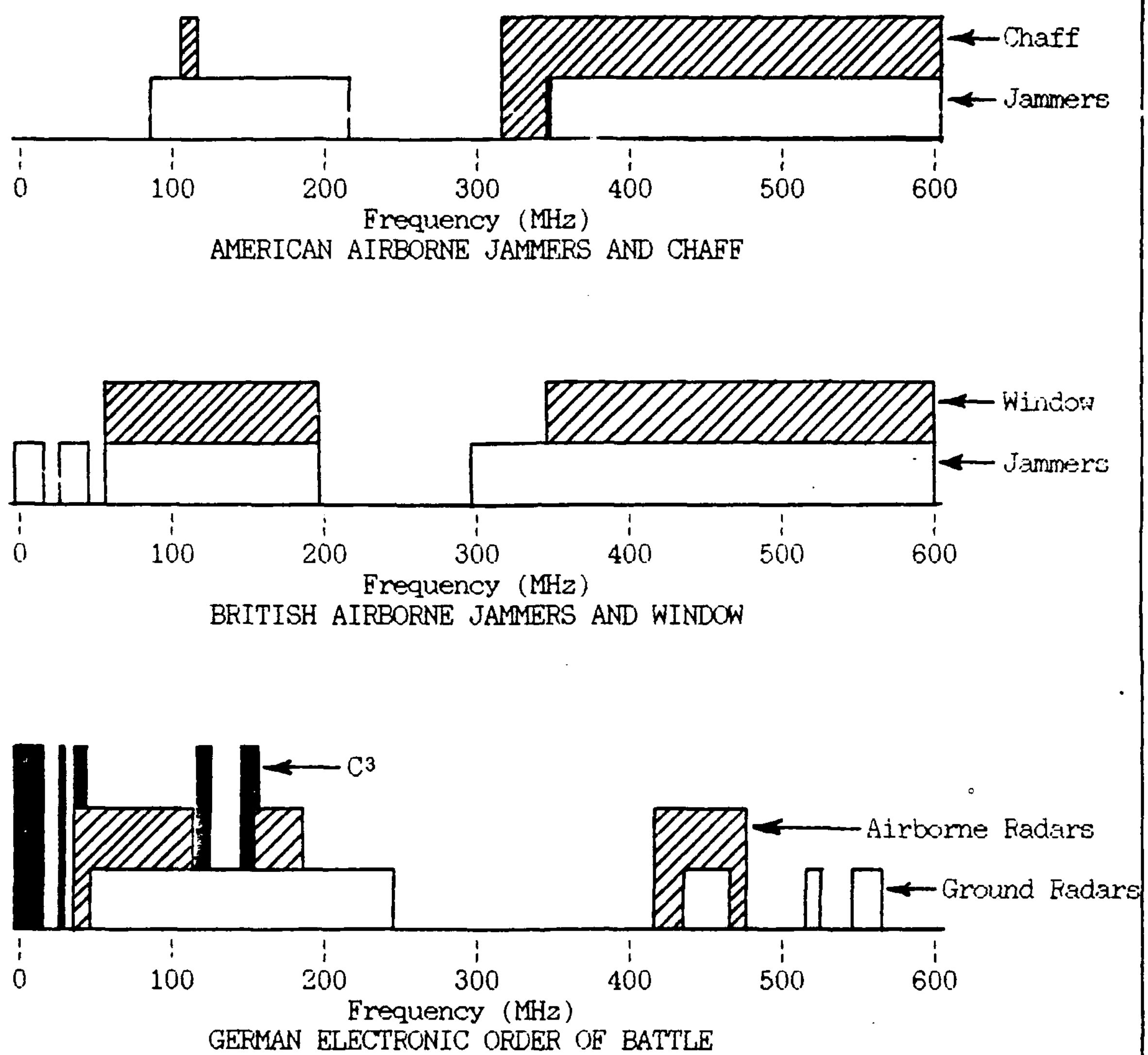
Figure 2. German Airborne Intercept Links



Note

The above information has been collated from material previously cited in the text.

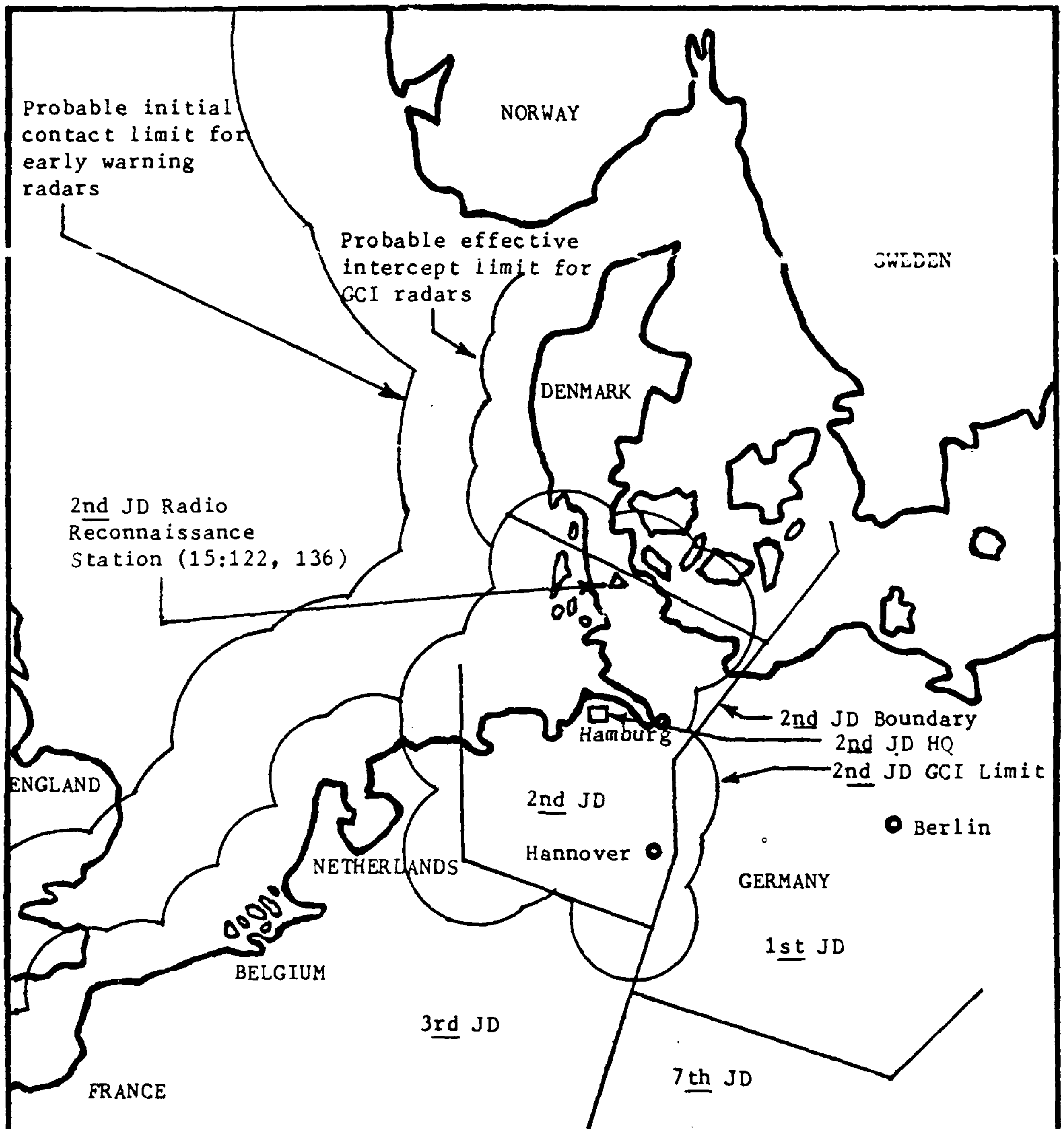
Figure 3. German Flak Links



Note

German EOB bands depend on when older systems were modified to expand their capability. In addition, some jammer coverages were intermittent because of anti-homing shutoff, different coverages of main force and No. 100 Group bombers, and the requirement to find and spot jam the emitters in some bands. The above information has been collated from material previously cited in the text. See Tables 1 through 7.

Figure 4. Comparison of German and Allied Frequency Coverage



NOTE

1. This figure shows the boundary of the 2nd Jagddivision and the probable limits of its GCI coverage as of June 1944. The limits of coastal early warning and GCI radars are included for comparison purposes. Coverages are for 15,000 feet.

2. Extracted from Post Hostilities Investigation: German Air Defenses, Vol II. (16:Figure 18)

Figure 5. 2nd Jagddivision Radar Coverage

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